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COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

STEERING GROUP MEETING

Takamatsu, Japan, 16 to 20 October 2023

Agenda Item 7: Integrated Dual Stringency Analysis

CO_2 AND NOISE TECHNOLOGY RESPONSE USING PUBLICLY ACCESSIBLE DATA SOURCES

(Presented by the United States of America)

1. INTRODUCTION

1.1 Due to data sharing restrictions encountered during this CAEP cycle, work on the dual stringency standards setting elements of the CAEP/13 Work Programme has been challenging. In response, the United States (U.S.) has been working to develop an alternative growth and replacement database (GRdb) based on publicly accessible data sources to serve as an alternative option if necessary. This alternative GRdb (alt-GRdb) contains a complete set of technology responses (TR) for all aeroplanes to all proposed CO_2 and noise stringency option (SO) combinations under consideration for the dual stringency. The development of this alt-GRdb can serve two purposes:

1.1.1 The alt-GRdb was initially conceived as a potential backup to the non-public GRdb (using Original Equipment Manufacturer [OEM] data) developed by the Data Processing and Analysis ad-hoc group (DPAahg), to be available in the event that data sharing issues could not be resolved. This would address transparency concerns that have been raised regarding the approach of using the DPAahg-developed GRdb, for which access is only allowed to those conducting the stringency analysis modelling. Now that data restrictions are being lifted, the DPAahg generated GRdb will be more widely circulated within CAEP and there is less of an immediate need for this alt-GRdb to be used in the dual stringency main analysis.

1.1.2 There is value, however, in investigating alternative data sources to those provided by the OEMs for standards-setting purposes. This alt-GRdb is based on data sources that are accessible to the public. The alt-GRdb provides a potential basis to investigate how such publicly accessible data sources could be used by CAEP in future standard setting efforts. Using publicly accessible data sources could help both to improve transparency and to serve as a basis for evaluating OEM-provided TRs. Section 7 describes additional work that could be undertaken to bring this concept to a level where it might be considered for use in CAEP standards-setting activities.

1.2 The purpose of this work is to analyze aeroplane CO_2 and Noise TRs to all CO_2 and noise SO combinations based on publicly accessible aeroplane performance data. The work conducted to date was divided into three phases, described as follows, with interim Phase 1 and Phase 2 versions of the alt-GRdb provided to members of WG1, WG3, MDG, and FESG for review and comment as they were developed. The three phases of work were:

— Aeroplanes > 60T MTOM (kg) (Phase 1)

— Air transport aeroplanes < 60T MTOM (kg) (Phase 2)

— Business and general aviation (BGA) aeroplanes < 60T MTOM (kg) (Phase 3)[1]

1.3 The result of this work is an alternative GRdb that can be freely shared within, or at some point outside of, CAEP and is included as an attachment to this paper.

1.4 This Information Paper outlines the methodology and data sources used to develop the alternative GRdb, an explanation and example of how the TRs were developed, along with an initial discussion of pros/cons of this approach, and an initial scoping of future work needed to improve the methodology.

2. METHODOLOGY

2.1 The United States first brought Fix 1 type TRs2 to WG3 as part of the CAEP/10 CO_2 standard setting process. The United States developed and publicly released a dataset similar to the CAEP GRdb in order to aid the United States' domestic adoption of the CAEP/10 CO_2 standards. The methodology used this cycle builds on this past work and follows the same assumptions and methodology agreed to by CAEP for the OEM TRs. Technology responses for each aeroplane for each CO_2 and noise stringency option combination were developed in four basic steps:

2.1.1 **Step 1**: Aeroplane CO_2 metric values (MV) and Noise performance were plotted against respective SOs across the MTOM spectrum to determine margins to proposed SOs and where aeroplanes failed. Charts showing the CO_2 MVs and cumulative noise plotted over their respective proposed SOs are included as Appendix A.

2.1.2 **Step 2:** As with the OEM TRs, the family approach was used where TRs would be based on the variant from each aeroplane family that was the first to fail. (See Appendix B below)

2.1.3 **Step 3:** The technology applicability and benefits for each family were reviewed and the TRs for each SO combination for the first to fail variants of each aeroplane family were built up. (Discussed more below in section 4)

[1] Due to paper deadlines, Phase 3 was not able to be shared with WG1 and WG3 ahead of its inclusion here.
[2] Per CAEP-SG/20232-IP/05, "Fix 1" technology responses are small change (e.g., a performance improvement package), "Fix 2" is a derivative aeroplane (e.g., re-engine), and "Fix 3" is a new aeroplane.

2.1.4 **Step 4**: TRs were applied to each member of the aeroplane family, and it was ensured that TRs are sufficient to meet all SO combinations for all aeroplane family members. (Example shown in section 1 below)

2.2 For ease of use within CAEP, results have been output in the format of the GRdb generated by DPAahg. The complete alt-GRdb based on publicly available data sources is included here as Attachment 1.

2.3 Interim versions of the database were shared with WG1 and WG3. Due to time schedule pressures of dual stringency, reviews of those interim versions did not occur. Moreover, the full version of the alt-GRdb was not able to be shared ahead of this paper for review by WG1 and WG3, also due to time pressures. In order to assess and improve the methodology, TRs would need to be reviewed jointly by WG1 and WG3, as some of the TRs have fuel burn and noise interdependencies.

3. DATA SOURCES

3.1 Relevant aeroplane models and their attributes came from the CAEP-confidential version of GRdb developed by DPAahg (see CAEP-SG/20232-IP/05).

3.2 Priority was given to using certified data for cumulative noise and CO_2 MV where possible.

3.2.1 Aeroplane cumulative noise values are certified values from the EASA noise database.

3.2.2 Although actual certified values were used in the few cases where aeroplanes have been certified to meet the CAEP/10 CO_2 standards and the MVs have been publicly reported, most aeroplanes have not yet been certified to the CAEP/10 CO_2 standards. Thus, aeroplane CO_2 MVs were developed using the commercially available Piano 5 (Piano version 5.4) aeroplane analysis tool.

3.3 CO_2 TRs were selected from the U.S. Research Team's (U.S. RT) aeroplane CO_2 technology and cost model, described further in section 4.

3.4 The U.S. RT researched incremental noise technology improvements to inform development of a non-recurring cost methodology (see CAEP-SG/20232-IP/05, Section 13), among other purposes. The team leveraged this work to develop noise benefits for incremental CO_2 technologies. As described below, these benefits were used in the TR analysis to achieve noise improvement levels up to the point where CO_2 benefits trade for noise benefits (for an example of this, see Figure 3b below).

4. TECHNOLOGY RESPONSES

4.1 Technology responses range from incremental changes to a given aeroplane's production technology mix (Fix 1's) to designing brand new aeroplanes from a clean sheet of paper (Fix 3's). Examples of the various fix types are shown in Table 1.

Improvement / Tech Insertion Examples	U.S. RT Nomen-clature	CAEP13 Nomen-clature	Magnitude of CO2 MV Benefit	Magnitude of NRC Required	Frequency
Clean Sheet Design	Significant Redesign	Fix 3	>10% CO_2 MV	$10-25B	Once per generation (every 20-30 years)
Re-Wing	Significant Redesign	Fix 2	>10% CO_2 MV	$5-10B	Once per generation (every 20-30 years)
Re-Engine	Significant Redesign	Fix 2	>10% CO_2 MV	$2B	Once per generation (every 20-30 years)
Small changes to the build standard after Entry Into Service (e.g., winglet, improve turbine blade profile)	Incremental Tech Insertion	Fix 1	<10% CO_2 MV	$50-300M	Several times during the production life of a program

Table 1 **– Types of Technology Responses**

4.2 During the CAEP/10 CO_2 standard development, the United States conducted an extensive primary and secondary research program and developed a technology and cost model for Fix 1 TRs in particular. Figure 1 shows an overview of this model.

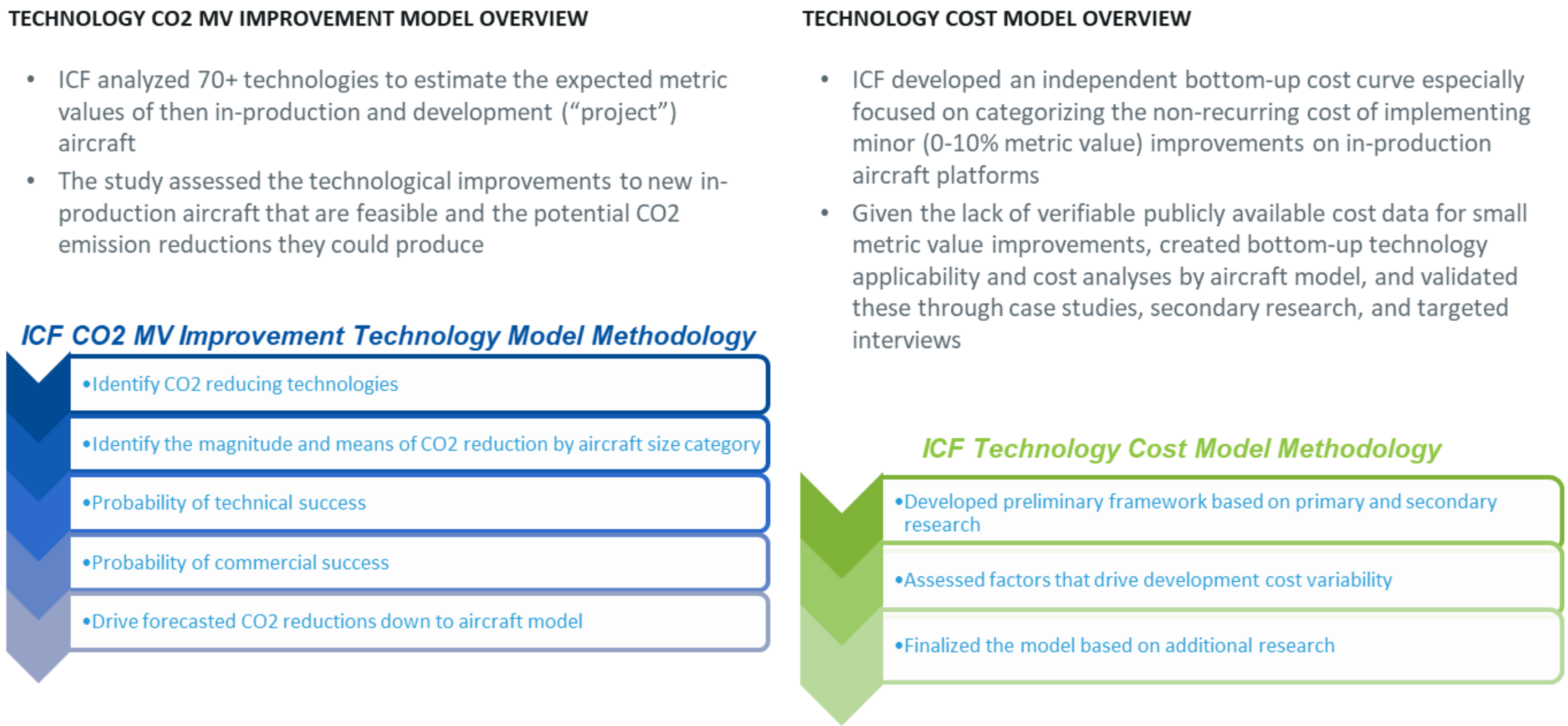

Figure 1 – U.S. RT CO_2 MV Technology and Cost Model Overview

4.3 This model was refreshed for use in CAEP/13 dual stringency analysis. Table 2 summarized the updates made to the model for the CAEP/13 cycle.

Key Questions	Result / Recommended Change	Rationale
Should any technologies be added?	Create an Aerodynamic Cleanups category	• Although unique, the A350 wing twist did not fit well into an existing airframe aerodynamic improvement category • Although retrofits are not in the project scope, certain airframe retrofit technologies identified did not fit well into an existing airframe aerodynamic improvement category either
Should any technologies be removed?	Hybrid Laminar Flow Control (HLFC) – Empennage should be removed	• HLFC was implemented on 787-9 but removed from the -10 and is not being implemented on the 777X • The technology appears to be commercially infeasible
Should the benefit ceiling for engine technologies be increased?	Keep the existing ceiling	• 17 engine technologies were analyzed • The magnitude of engine improvements were in line with the model
Can we expect the magnitude of fuel burn improvements to be the same for current generation aeroplanes as they were for previous generation aeroplanes?	Retain the existing assumptions	• 6 technology insertions on latest generation aeroplanes were identified (5 engine, 1 non-engine) • For engine technologies, the magnitude of improvements remains the same • For non-engine technologies, data points are limited

Table 2- Updates to U.S. RT Technology and Cost Model for Use in CAEP/13

4.4 Table 3 shows the most impactful CO_2 reduction technologies in the Fix 1 category.

Technology	Small BGA		Large BGA		Turboprop		Regional Jet		Single Aisle		Small Twin Aisle		Large Twin Aisle	
	MV%	NRC	MV%	NRC	MV%	NRC	MV%	NRC	MV%	NRC	MV%	NRC	MV%	NRC
Engine Technologies	2.0%	$70	2.0%	$131	2.0%	$63	2.0%	$139	2.0%	$200	2.3%	$382	2.3%	$473
Advanced Wingtip Devices	3.5%	$103	3.5%	$137	3.5%	$137	3.5%	$137	3.5%	$173	3.5%	$207	3.5%	$207
Aft Body Aerodynamics	1.0%	$169	1.3%	$224	1.3%	$224	1.3%	$224	1.3%	$282	1.3%	$338	1.3%	$338
ECS Aero and On-Demand ECS	0.6%	$38	0.6%	$49	0.6%	$49	0.6%	$49	0.6%	$64	0.6%	$76	0.6%	$76
Adaptive Trailing Edge	0.0%	$136	2.0%	$181	0.5%	$181	0.5%	$181	1.3%	$228	2.0%	$272	2.0%	$272
Riblet Coatings	0.5%	$136	0.5%	$181	0.5%	$181	0.5%	$181	1.0%	$228	1.5%	$272	1.5%	$272

Other less impactful but still relevant technologies include: Reducing Profile of the Lights, Natural Laminar Flow Control – Nacelle Control Surface – Optimal Control Laws for Horizontal Stabilizer, Gap Reductions, and Aft Body Redesign.

Table 3 - Metric Value Improvements and Non-Recurring Costs (NRC, $M) by Technology by Aeroplane Size Category for the Most Impactful CO_2-Reducing Technologies

4.5 Some CO_2-improving technologies also had beneficial effects on noise. The combined CO_2- and noise- improving Fix 1 technologies along with their estimated NRCs from the U.S. RT’s model are shown in Table 4.

Technology	Small BGA			Large BGA			Turboprop			Regional Jet			Single Aisle			Small Twin Aisle			Large Twin Aisle		
	MV%	Noise	NRC	MV%	Noise	NRC	MV%	Noise	NRC	MV%	Noise	NRC	MV%	Noise	NRC	MV%	Noise	NRC	MV%	Noise	NRC
Engine Technologies	2.0%	-	$70	2.0%	1.1	$131	2.0%	-	$63	2.0%	1.4	$139	2.0%	1.4	$200	2.3%	1.4	$382	2.3%	1.4	$473
Advanced Wingtip Devices	3.5%	0.4	$103	3.5%	0.4	$137	3.5%	0.4	$137	3.5%	0.4	$137	3.5%	1.1	$173	3.5%	1.1	$207	3.5%	1.1	$207
Aft Body Aerodynamics	1.0%	-	$169	1.3%	-	$224	1.3%	-	$224	1.3%	-	$224	1.3%	-	$282	1.3%	-	$338	1.3%	-	$338
ECS Aero and On-Demand ECS	0.6%	-	$38	0.6%	-	$49	0.6%	-	$49	0.6%	-	$49	0.6%	-	$64	0.6%	-	$76	0.6%	-	$76
Adaptive Trailing Edge	0.0%	0.25	$136	2.0%	0.25	$181	0.5%	0.25	$181	0.5%	0.25	$181	1.3%	0.5	$228	2.0%	0.5	$272	2.0%	0.5	$272
Riblet Coatings	0.5%	-	$136	0.5%	-	$181	0.5%	-	$181	0.5%	-	$181	1.0%	-	$228	1.5%	-	$272	1.5%	-	$272

Other less impactful but still relevant technologies include: Reducing Profile of the Lights, Natural Laminar Flow Control – Nacelle Control Surface – Optimal Control Laws for Horizontal Stabilizer, Gap Reductions, Aft Body Redesign

Source: ICF analysis. Noise = assumed benefits (dB).
In the technology response analysis, the above figures were customized to individual aircraft models.

Table 4 - Metric Value Improvements and Non-Recurring Costs (NRC, $M) by Technology by Aeroplane Size category (most impactful technologies)

5. EXAMPLE TECHNOLOGY RESPONSE ANALYSIS

5.1 For every given aeroplane, its CO_2 MV and noise performance were identified, its pass/fail status for every SO combination was derived, and its margin to each SO combination before TR was calculated. The variants first to fail for both CO_2 and noise were identified (see Table 5 below and Appendix B for a complete list of first to fail aeroplane variants). This is illustrated below in Figure 2 using the A330-900, the member of the A330 family that fails first.

Aeroplane Family	Aeroplane Variant	First to Fail	
		CO₂	***Noise***
A330neo | Trent 7000	A330-800 | Trent 7000	Y	
	A330-900 | Trent 7000		Y

Table 5 - First A330neo models to fail

First to Fail CO_2 Variant (A330-800)

CO_2 Margin before TR (-800)

CO2	Noise: NSO A	NSO B	NSO C	NSO D	NSO E
NT A	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
NT B	-2.3%	-2.3%	-2.3%	-2.3%	-2.3%
NT C	-4.4%	-4.4%	-4.4%	-4.4%	-4.4%
NT D	-6.5%	-6.5%	-6.5%	-6.5%	-6.5%
NT E	-8.5%	-8.5%	-8.5%	-8.5%	-8.5%
NT F	-10.6%	-10.6%	-10.6%	-10.6%	-10.6%
NT G	-14.7%	-14.7%	-14.7%	-14.7%	-14.7%
InP A	2.8%				
InP B	0.7%				
InP C	-2.3%				
InP D	-4.4%				

First to Fail Noise Variant (A330-900)

Noise Margin before TR (-900)

CO2	Noise: NSO A	NSO B	NSO C	NSO D	NSO E
NT A	4.6	2.6	0.6	-1.4	-3.4
NT B	4.6	2.6	0.6	-1.4	-3.4
NT C	4.6	2.6	0.6	-1.4	-3.4
NT D	4.6	2.6	0.6	-1.4	-3.4
NT E	4.6	2.6	0.6	-1.4	-3.4
NT F	4.6	2.6	0.6	-1.4	-3.4
NT G	4.6	2.6	0.6	-1.4	-3.4
InP A	N/A				
InP B					
InP C					
InP D					

A330neo Family Performance

Margin before TR

CO2	Noise: NSO A	NSO B	NSO C	NSO D	NSO E
NT A	4.6 -0.3%	2.6 -0.3%	0.6 -0.3%	-1.4 -0.3%	-3.4 -0.3%
NT B	4.6 -2.3%	2.6 -2.3%	0.6 -2.3%	-1.4 -2.3%	-3.4 -2.3%
NT C	4.6 -4.4%	2.6 -4.4%	0.6 -4.4%	-1.4 -4.4%	-3.4 -4.4%
NT D	4.6 -6.5%	2.6 -6.5%	0.6 -6.5%	-1.4 -6.5%	-3.4 -6.5%
NT E	4.6 -8.5%	2.6 -8.5%	0.6 -8.5%	-1.4 -8.5%	-3.4 -8.5%
NT F	4.6 -10.6%	2.6 -10.6%	0.6 -10.6%	-1.4 -10.6%	-3.4 -10.6%
NT G	4.6 -14.7%	2.6 -14.7%	0.6 -14.7%	-1.4 -14.7%	-3.4 -14.7%
InP A	2.8%				
InP B	0.7%				
InP C	-2.3%				
InP D	-4.4%				

PASS FAIL

Figure 2 - Pass/Fail Status and Margin Before Technology Response for the A330

5.2 Next, for SO combinations for which the aeroplane fails one or both standards, TRs were selected to fix the aeroplane to the standard. Naturally, this means Fix 1 improvements were utilized first. Once the Fix 1 improvements were exhausted, Fix 2 or Fix 3 responses were then employed. Table 6 and Figure 3 show the TRs for the A330neo family for CO_2 SOs and noise SO -8dB.

						NSO A	NSO A	NSO A	NSO A	NSO A	NSO A	NSO A	N/A	N/A	N/A	N/A
Technology	**Applicable?**	**FB Benefit**	**Noise Benefit**	**NRC**	**Comments**	**CSO NT A**	**CSO NT B**	**CSO NT C**	**CSO NT D**	**CSO NT E**	**CSO NT F**	**CSO NT G**	**CSO InP A**	**CSO InP B**	**CSO InP C**	**CSO InP D**
Adaptive Trailing Edge	Y	2.00%	0.5	$272			X	X	X	X					X	X
Advanced Wingtip Devices - Retrofit	Y	1.00%	0.4	$207					X	X						
Riblet Coatings	Y	1.50%	0	$272				X	X	X						X
Natural Laminar Flow Control - Nacelle	Y	0.55%	0	$469												
Composites - Current State Increased Application	Y	0.25%	0	$403												
ECS Aero and On Demand ECS Scheduling	Y	0.63%	0	$76		X	X			X					X	
Control Surface - Optimal Control Laws for horizontal sta	Y	0.38%	0	$207												
Gap Reductions - Slats, Spoilers, etc.	Y	0.15%	0	$76												
Reducing Profile of the Lights	Y	0.15%	0	$10						X						
Aerodynamic APU Fairing / Aft body redesign	Y	1.25%	0	$338						X						
Fix 2	Y	11.50%	7	$3,000							X					
Fix 3	Y	16.88%	10	$12,000								X				
Engine Technologies	Y	2.00%	1.4	$380				X	X	X						X

Table 6a - Example Technology Response Buildup – A330neo Family (NT A through G and InP A through D for NSO A)

						NSO A	NSO B	NSO C	NSO D	NSO E
Technology	**Applicable?**	**FB Benefit**	**Noise Benefit**	**NRC**	**Comments**	**CSO NT A**	**CSO NT A**	**CSO NT A**	**CSO NT A**	**CSO NT A**
Adaptive Trailing Edge	Y	2.00%	0.5	$272						
Advanced Wingtip Devices - Retrofit	Y	1.00%	0.4	$207						
Riblet Coatings	Y	1.50%	0	$272						
Natural Laminar Flow Control - Nacelle	Y	0.55%	0	$469						
Composites - Current State Increased Application	Y	0.25%	0	$403						
ECS Aero and On Demand ECS Scheduling	Y	0.63%	0	$76		X	X	X		
Control Surface - Optimal Control Laws for horizontal sta	Y	0.38%	0	$207						
Gap Reductions - Slats, Spoilers, etc.	Y	0.15%	0	$76						
Reducing Profile of the Lights	Y	0.15%	0	$10						
Aerodynamic APU Fairing / Aft body redesign	Y	1.25%	0	$338						
Fix 2	Y	11.50%	7	$3,000						X
Fix 3	Y	16.88%	10	$12,000						
Engine Technologies	Y	2.00%	1.4	$380					X	

Table 6b - Example Technology Response Buildup – A330neo Family (NSO A through E for NT A)

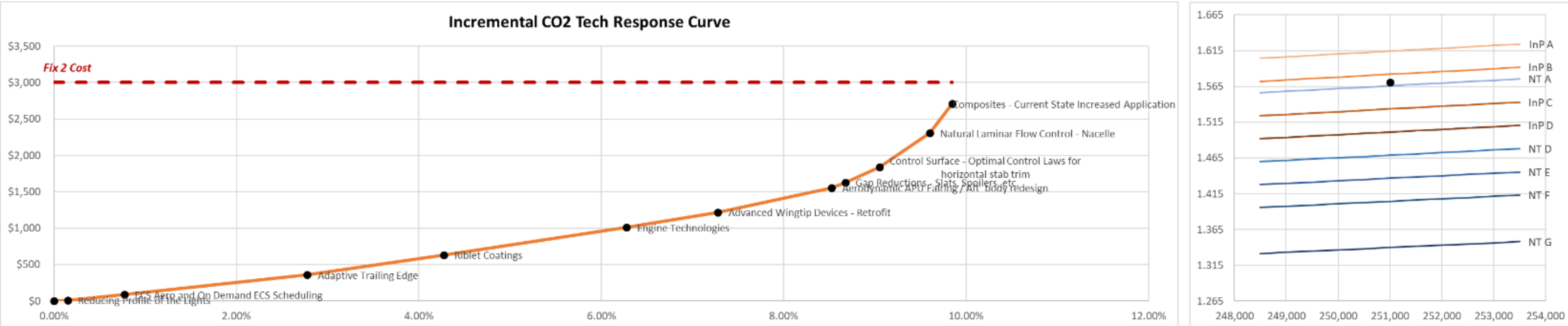

Figure 3a – Incremental CO2 technology supply curve (A330-800)

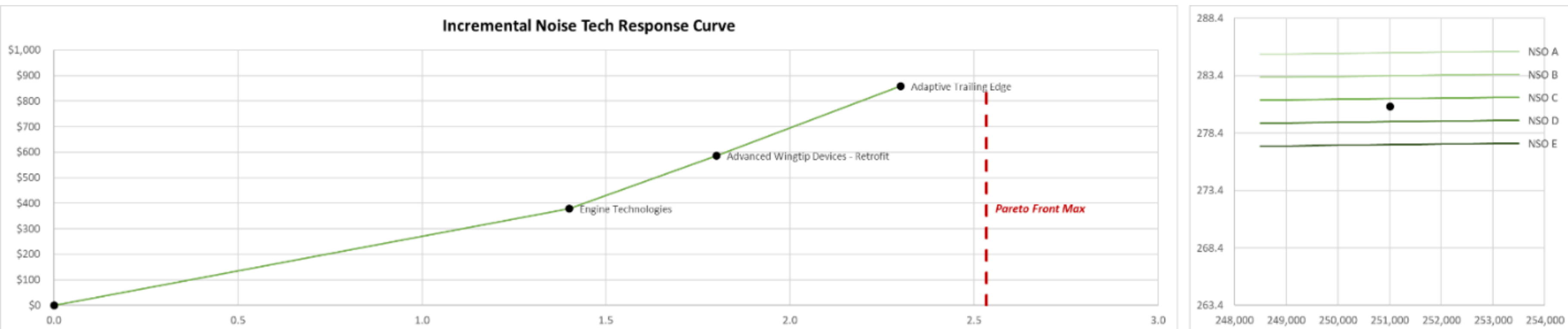

Figure 3b – Incremental Noise technology supply curve (A330-900)

5.3 Once the first to fail family member was fixed to the standard, these TRs were applied to every other member of the family and each was checked to ensure all members meet the standard after TR, as shown in Figure 4.

Fix Type

CO2	Noise: NSO A	NSO B	NSO C	NSO D	NSO E
NT A	Fix 1	Fix 1	Fix 1	Fix 1	Fix 2
NT B	Fix 1	Fix 1	Fix 1	Fix 1	Fix 2
NT C	Fix 1	Fix 1	Fix 1	Fix 1	Fix 2
NT D	Fix 1	Fix 1	Fix 1	Fix 1	Fix 2
NT E	Fix 1	Fix 1	Fix 1	Fix 1	Fix 2
NT F	Fix 2	Fix 2	Fix 2	Fix 2	Fix 2
NT G	Fix 3	Fix 3	Fix 3	Fix 3	Fix 3
InP A	None				
InP B	None				
InP C	Fix 1				
InP D	Fix 1				

Tech Response Applied

CO2	Noise: NSO A	NSO B	NSO C	NSO D	NSO E
NT A	*0* 0.3%	*0* 0.3%	*0* 0.3%	*1.4* 0.3%	*3.4* 0.3%
NT B	*0* 2.3%	*0* 2.3%	*0* 2.3%	*1.4* 2.3%	*3.4* 2.3%
NT C	*0* 4.4%	*0* 4.4%	*0* 4.4%	*1.4* 4.4%	*3.4* 4.4%
NT D	*0* 6.5%	*0* 6.5%	*0* 6.5%	*1.4* 6.5%	*3.4* 6.5%
NT E	*0* 8.5%	*0* 8.5%	*0* 8.5%	*1.4* 8.5%	*3.4* 8.5%
NT F	*0* 10.6%	*0* 10.6%	*0* 10.6%	*1.4* 10.6%	*3.4* 10.6%
NT G	*0* 14.7%	*0* 14.7%	*0* 14.7%	*1.4* 14.7%	*3.4* 14.7%
InP A	0%				
InP B	0%				
InP C	2.3%				
InP D	4.4%				

ICF NRC ($M)

CO2	Noise: NSO A	NSO B	NSO C	NSO D	NSO E
NT A	$76	$76	$76	$380	$3,000
NT B	$348	$348	$348	$455	$3,000
NT C	$924	$924	$924	$924	$3,000
NT D	$1,131	$1,131	$1,131	$1,131	$3,000
NT E	$1,554	$1,554	$1,554	$1,554	$3,000
NT F	$3,000	$3,000	$3,000	$3,000	$3,000
NT G	$12,000	$12,000	$12,000	$12,000	$12,000
InP A	$0				
InP B	$0				
InP C	$348				
InP D	$924				

Figure 4 - Pass / Fail Status and Margin After Technology Response for the A330-900

6. DISCUSSION

6.1 Work on the alt-GRdb was initiated to provide a potential backup option due to the data sharing and transparency issues that arose. While we believe this dataset could be used for that purpose, we also recognize that additional work would have been necessary to resolve the unique limitations with the alternative dataset this cycle. In light of the removal of restrictions on the DPAahg-generated non-public GRdb (using OEM data) and ability to use that for the Main Analysis, we have an opportunity to investigate and refine an alternative approach to OEM-provided technology responses along with if or how an alternative approach could be used in a future CAEP standard setting process. Such an approach could serve to increase transparency and either serve as a basis for evaluating OEM-provided TRs or replace them. Below are some initial observations of some of the uses and limitations of this approach as it currently stands, along with initial thoughts on how it may change or could be improved for future CAEP work.

6.2 Initial discussions within FESG, MDG, WG1, and WG3 highlighted some of the challenges with the alt-GRdb as it currently stands. Below is a discussion of what was done this cycle and some initial observations of what could be done to change or improve the approach in a future iteration of this effort.

6.3 **Schedule to develop an Alternative GRdb** – *This cycle* – Work to develop the draft alt-GRdb started later in this cycle and was conducted solely by the United States as it was not an official work item for the working groups. Additionally, while draft versions of the alt-GRdb were shared informally with members of WG1, WG3, MDG, and FESG, they have not had time to review the proposed TRs due to higher priority work items and the final version is only now available for them to review. Additional time is needed to allow additional review, verification, and input to be provided.

6.3.1 *Future cycles* – Developing the alt-GRdb was a significant workload for the United States to take on alone. Starting to develop this dataset at the very beginning of the CAEP cycle, as is normal for the GRdb, would greatly help. Additionally, spreading the workload over more parties/organizations would reduce overall workload, expand technical input, and provide greater time for review and discussion. For example, this would allow countries time to develop TRs for their domestic manufacturers.

6.4 **Data quality for Alternative GRdb**: InP – *This cycle* – The GRdb should be based on certified data for in-production aeroplanes wherever possible. This cycle, noise is based on certified data from the EASA Noise database. However, CO_2 MV certification data is not yet available for most aeroplanes to use this cycle. The non-public GRdb will be based on manufacturer estimated CO_2 MVs in place of certification data. These estimates were not available for this alt-GRdb. Thus, Piano software was used to generate CO_2 MV data as it was determined to be the best publicly accessible information. Based on an analysis by DPAahg, Piano data was shown to be reasonably accurate for large aeroplanes. The DPAahg has noted that uncertainties are greater with smaller aeroplanes, and how to use Piano data for smaller aeroplanes would need to be addressed if this dataset were to be used in a standard setting analysis.

6.4.1 *Future cycles* – In the future, publicly available certified data will be available for all pollutants for all in-production aeroplanes. For engine standards, the Engine Emissions Databank could be used in the same manner as NoiseDb for certified data. Also, the CO_2 metric value database will be populated and available for future CO_2 standards. Thus, secondary sources, such as Piano, will not be necessary for InP aeroplanes in the future.

6.5 **Data Quality for Alternative GRdb: Project Aeroplanes** – Data challenges for project aeroplanes will always exist because they are not certified products. In the alt-GRdb, CO_2 MVs were based on Piano estimates; however, no good estimate was found to allow the calculation of noise values for project aeroplanes. Various means have been used over different CAEP cycles to estimate project aeroplane/engine data. This cycle, OEMs provided estimates for their project aeroplane. In CAEP/10, project aeroplane CO_2 MVs were based on percent changes from existing products based on publicly accessible information. Further work is needed to consider the best method to estimate project aeroplane values. This is likely an area that would need to be evaluated each cycle to determine the best method to use.

6.6 **Technology responses for Alternative GRdb** – *This cycle* – Technology responses in the alt-GRdb were developed based on assessments of each aeroplane. For Fix 1's, a build-up of what technology could be applied is built up for each aeroplane and is available for review and discussion (see examples in section 1 above). This approach has the benefit that the WGs can evaluate individual TRs to ensure that they make sense – i.e., assess if an individual technology improvement might be over/underestimated, if two technologies cannot be applied together because they conflict, or if technology may not be expected to meet the technical feasibility definition. This level of transparency will also allow WGs to ensure that the technology response is applied in the same manner for all products and reduce uncertainty. As discussed in CAEP-SG/20232-IP/05, there was some potential variation with how manufacturers applied the WG1 and WG3 agreed definition of technical feasibility. Even if the TRs could have been viewed by all WG members, it would have been very challenging to understand where these differences in the OEM-GRdb may have been coming from due to the opaque manner in which they are provided. The approach used here can be used to increase transparency and evaluate OEM-provided TRs. Discussions and consultation with manufacturers regarding TRs would have been beneficial; however, that has not been possible due to the data sharing restrictions.

6.6.1 *Future cycles* – Gathering broader input by spreading the development of the TR out among members would allow more detailed evaluation of potential TRs by more technical experts and would better distribute the workload. Using an approach similar to that shown above, TRs can be evaluated and compared to ensure they are considered in similar manners, reflect differing capabilities, and reflect agreed ranges for what may be expected. Information could be gathered from a variety of places such as research programs, public-private partnerships, etc. to form the basis of the TRs. This open evaluation would provide additional transparency, along with robustness and confidence that assumptions are being applied in a consistent manner, so we can avoid the questions that have arisen this cycle. Consultation with manufacturers will still be a critical part of any TR development, and it would be a necessary component of any future process. Broader review and direct discussion with manufacturers would be beneficial improvements in the future.

6.7 **Uncertainty for Alternative GRdb** – *This cycle* – There may be greater uncertainty of the CO_2 MVs due to their estimation with Piano. This could potentially be addressed by including a "design margin" in the TR, as was included in CAEP/10. Aeroplanes could be assumed to over-comply by 1 or 2 percentage points to account for uncertainty in the CO_2MV. This uncertainty is larger for smaller aeroplanes than for large aeroplanes and may need to be address in different manner. Something similar needs to be done for project aeroplanes for CO_2 and Noise.

6.7.1 *Future cycle* – As noted in 6.4.1, noise, CO_2, or engine emission data would all be based on publicly available certified values. Therefore, there should be no additional uncertainty compared to OEM inputs. However, project aeroplanes will still be a challenge, and uncertainty may change depending upon how project airplanes are handled in future CAEP cycles.

7. FURTHER WORK

7.1 Recognizing workloads and timelines this CAEP cycle, any new or amended tasks should be well defined and describe where the resources to accomplish them will come from. Keeping this in mind, below is an initial scoping of how to further progress work this cycle on using publicly accessible data with the goal of providing a paper to the CAEP/13 meeting. Some work would be needed in WG1, WG3, MDG, and FESG, as described below.

7.2 *WG1 and WG3* – These working groups could review the TRs included in the alt-GRdb, in Attachment 1 to this information paper. Where questions are raised about any specific TR provided, the United States can provide more information to facilitate the discussion. The working groups could review and consider the methodology used to develop these TRs, how it could be improved, and whether a methodology could be developed that would allow this to be used in future cycles.

7.3 *MDG/FESG* – Following the WG1 and WG3 review of the alt-GRdb, limited model runs could be conducted. Recognizing the existing workload of MDG/FESG modelers, the United States is offering additional resources to accomplish CO_2 modelling, so that the Dual Stringency Main Analysis runs will not be affected. We would welcome the opportunity to work with others on possible noise modelling as well. The groups should also consider whether any other parts of the MDG or FESG modelling process would be affected if these alternate sources are used.

7.4 *Outcome* – WG1, WG3, MDG, and FESG could compile their findings in a final report to CAEP/13. This report could consider how items like data quality, robustness of methodology, transparency, or other benefits or drawbacks to using publicly accessible information to develop TRs may impact future CAEP standard setting activities. The United States is committed to taking the lead on developing such a report.

8. CONCLUSIONS

8.1 A complete GRdb based on publicly accessible data sources was developed.

8.2 This effort demonstrates that publicly accessible data sources are worth evaluating further with reviews by WGs. Section 7 outlines some of the work that could be conducted this cycle to further validate the approach, without diverting resources away from the Dual Stringency Main Analysis. The United States would volunteer to facilitate these discussions and provide additional modelling resources where needed to accomplish this ahead of the CAEP/13 meeting. The United States would welcome similar efforts from other CAEP members and observers and would be happy to assist with such efforts.

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ATTACHMENT 1

ALTERNATIVE GRDB DEVELOPED USING PUBLICLY ACCESSIBLE DATA SOURCES

[See file named: CAEPSG.20232.IP.018.7.en_Attachment 1_CAEP13_Alt-GRdb_v2.13P.xls]

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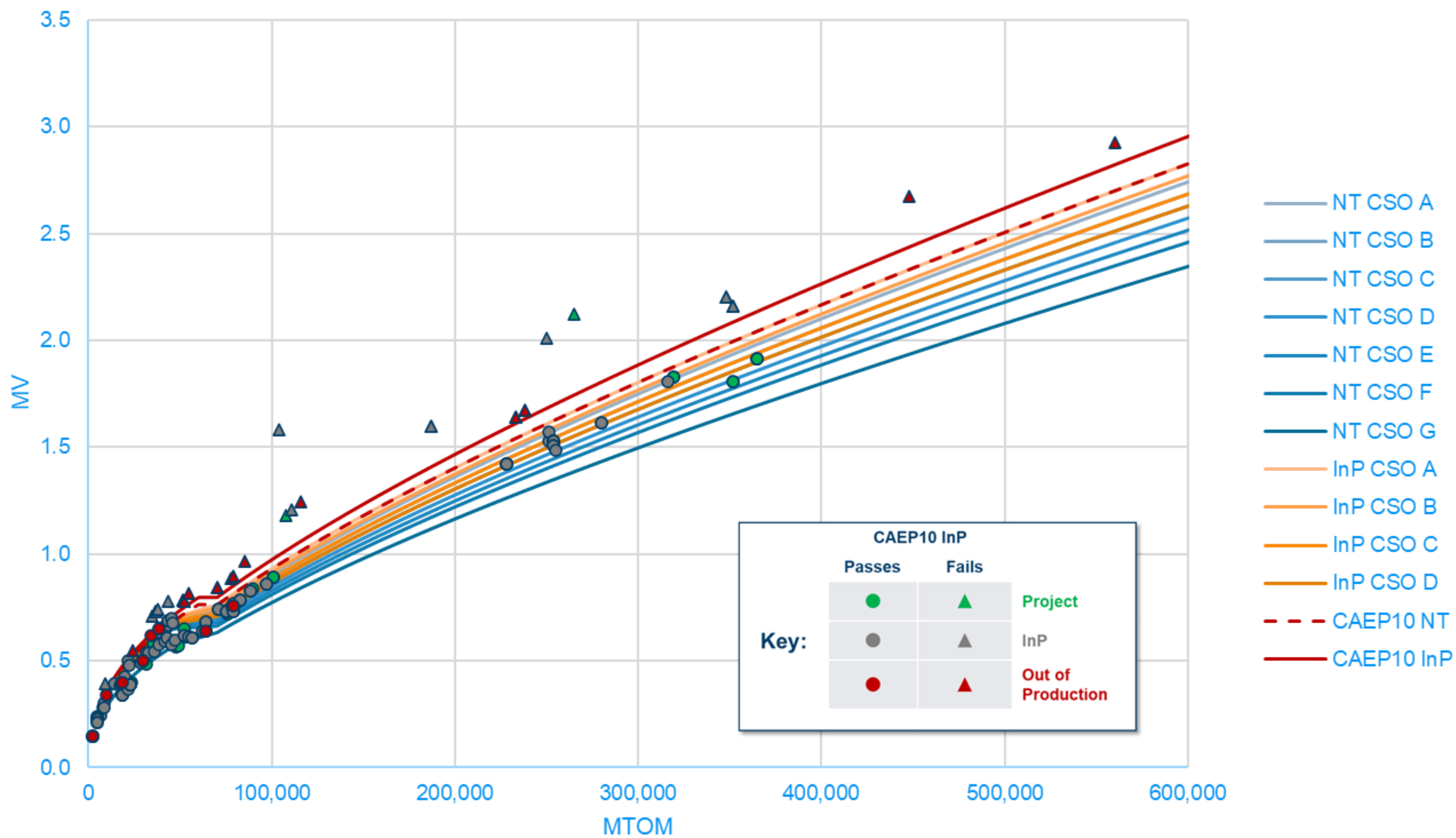
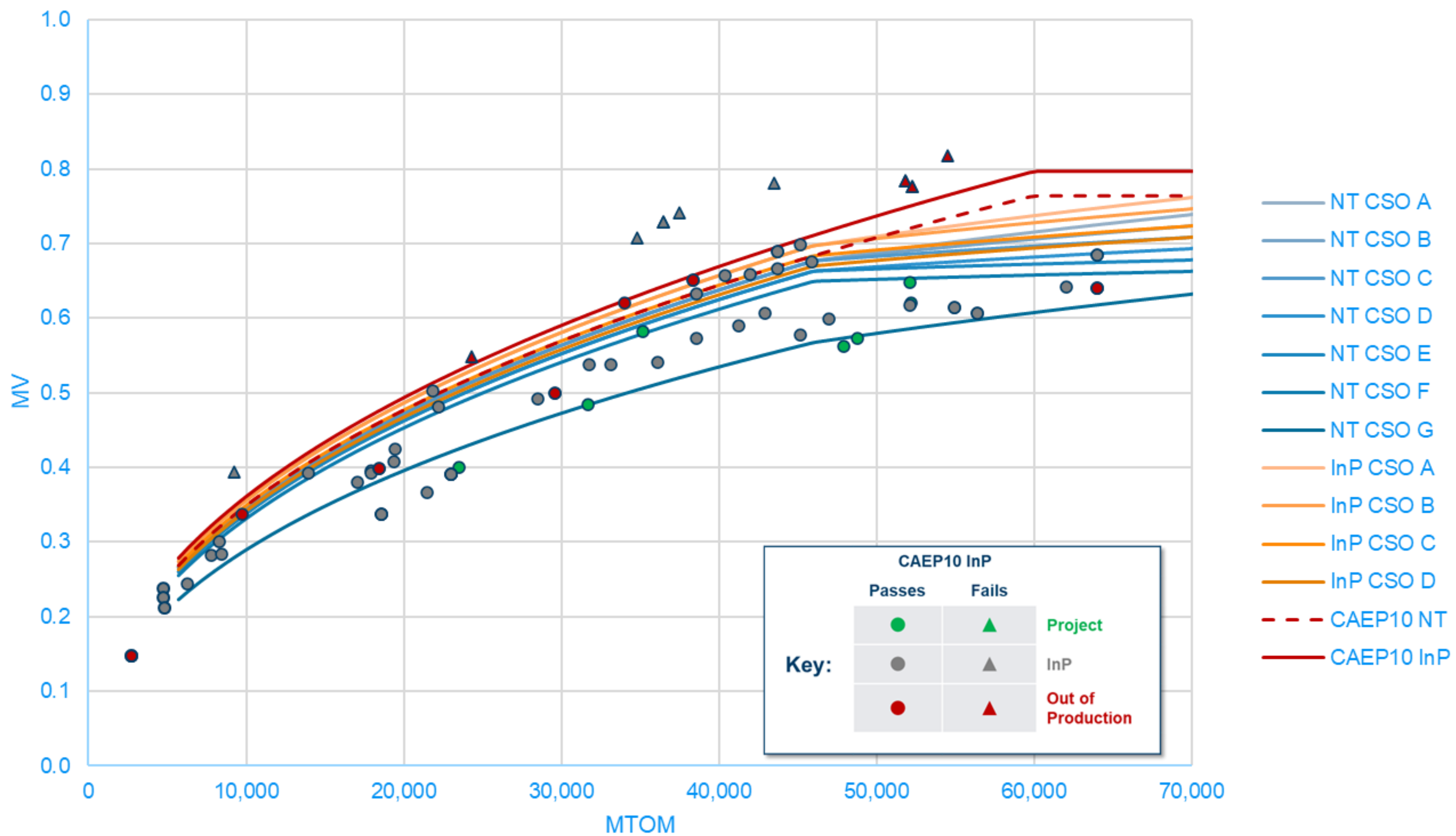
APPENDIX A

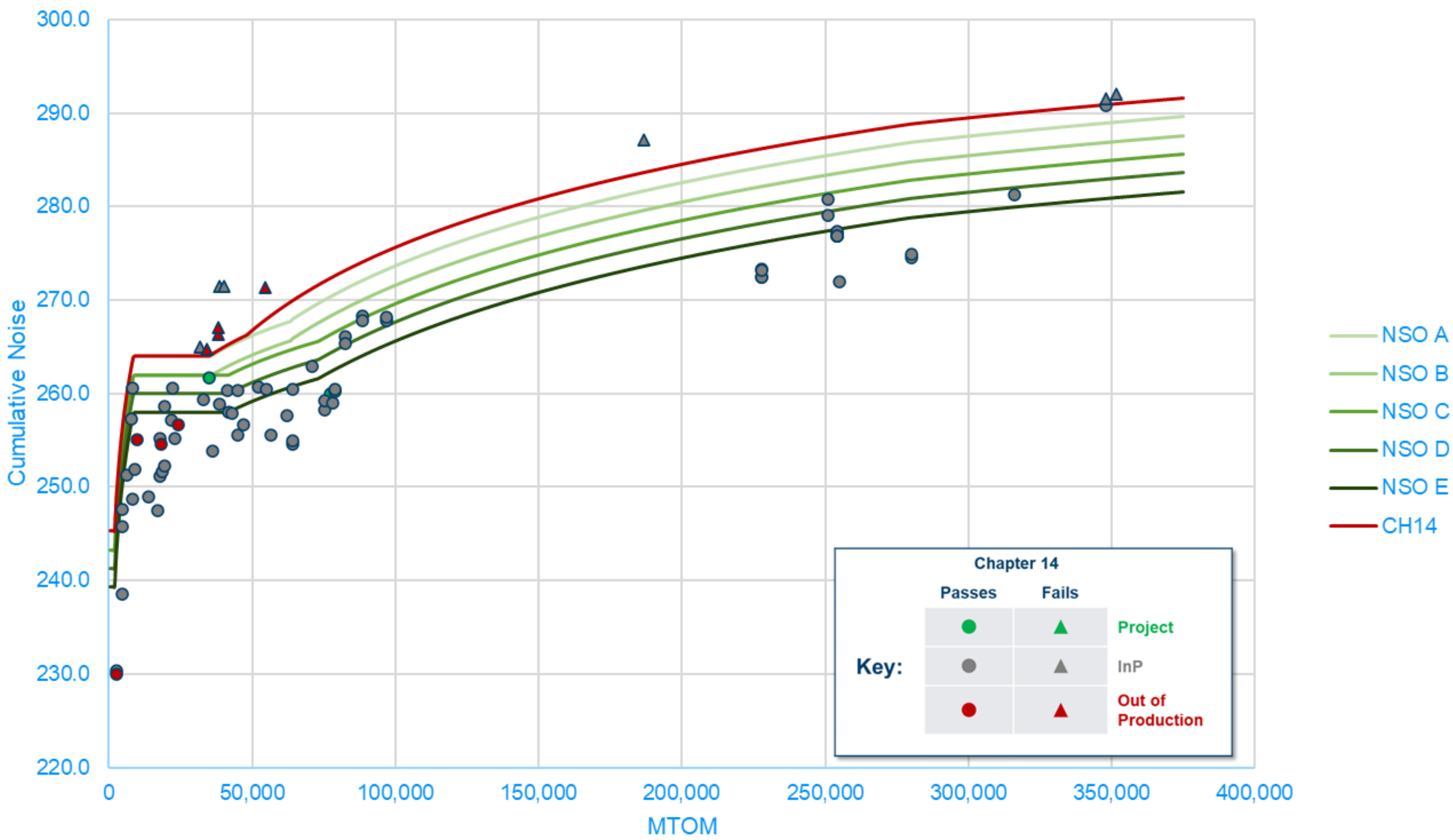
CO_2 METRIC VALUES & CUMULATIVE NOISE PLOTTED OVER PROPOSED CO_2 STRINGENCY OPTIONS

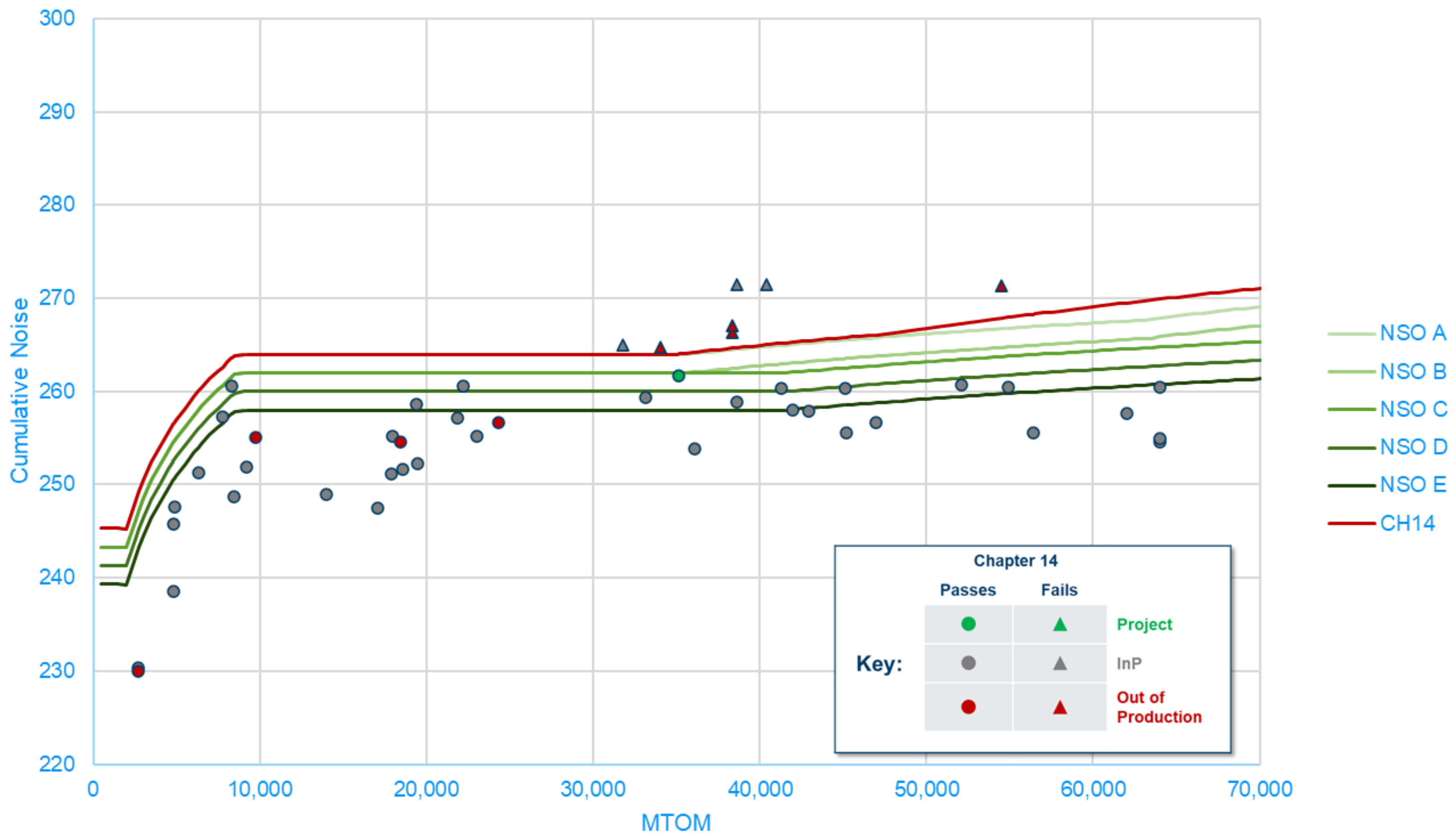
CO_2 Metric Values Plotted Over Proposed CO_2 Stringency Options




1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
MV
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
MTOM
CAEP10 InP
Passes
Fails
Key:
Project
InP
Out of Production
NT CSO A
NT CSO B
NT CSO C
NT CSO D
NT CSO E
NT CSO F
NT CSO G
InP CSO A
InP CSO B
InP CSO C
InP CSO D
CAEP10 NT
CAEP10 InP

Cumulative Noise Levels Plotted Over Proposed Noise Stringency Options (2 Engines Only)




300
290
280
270
260
250
240
230
220
Cumulative Noise
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
MTOM
NSO A
NSO B
NSO C
NSO D
NSO E
CH14
Chapter 14
Passes
Fails
Key:
Project
InP
Out of
Production

————————

APPENDIX B

FIRST TO FAIL AEROPLANE VARIANTS

Aeroplane Family	Aeroplane Variant	First to Fail	
		CO2	***Noise***
737MAX | LEAP-1B	737MAX-10 | LEAP-1B	Y	
	737MAX-9 | LEAP-1B		Y
777X | GE9X	777-8X | GE9X	Y	No Noise Data
787-8/9/10 | GEnx-1B	787-9 | GEnx-1B		Y
	787-9 BBJ | GEnx-1B	Y	
787-8/9/10 | Trent 1000	787-9 | Trent 1000		Y
	787-9 BBJ | Trent 1000	Y	
A220 | PW1500 Family	A220-300 | PW1521G	Y	Y
A320neo Family | LEAP-1A	A321neo (NX) | LEAP-1A		Y
	A321neo (NY) | LEAP-1A	Y	
A320neo Family | PW1100 Family	A321neo (NX) | PW1100 Family		Y
	A321neo (NY) | PW1100 Family	Y	
A330neo | Trent 7000	A330-800 | Trent 7000	Y	
	A330-900 | Trent 7000		Y
A350 | Trent XWB	A350-1000 | Trent XWB-97		Y
	A350-1000F | Trent XWB-97	Y	
An-140 | TV3-117	An-140 | TV3-117	Y	No Noise Data
An-148 | D-436	An-148-100 | D-436	Y	No Noise Data
An-225 | D-18T	An-225 | D-18T	Y	No Noise Data
An-24 | Al-20	An-32B | Al-20D	Y	No Noise Data
An-72 | D-36	An-74TK-300 | D-36	Y	No Noise Data
ARJ21 | CF34	ARJ21 | CF34	Y	No Noise Data
ATR42/72 | PW100 Family	ATR72-200 (EASA Noise) | PW127M		Y
	ATR72-200 | PW127M	Y	
C919 | LEAP-1C	C919 | LEAP-1C	Y	No Noise Data
Challenger 350 | HTF7000	Challenger 350 | HTF7000	Y	Y
Challenger 3500 | HTF7000	Challenger 3500 | HTF7000	Y	No Noise Data
Challenger 650 | CF34	Challenger 650 | CF34	Y	Y
Citation Jet Family | FJ44	Citation CJ4 | FJ44	Y	Y
Citation Jet Family | PW300 Family	Citation Latitude | PW300 Family	Y	Y
Citation Jet Family | HTF7000	Citation Longitude | HTF7000	Y	Y
Citation Jet Family | PW500 Family	Citation XLS+ | PW500 Family	Y	Y
E-170/175 | CF34	E-170 | CF34		Y

Aeroplane Family	Aeroplane Variant	First to Fail	
		CO2	***Noise***
	E-175 | CF34	Y	
E-190/195 E2 | PW1900 Family	E-195 E2 | PW1900 Family	Y	Y
Eclipse 550 | PW600 Family	Eclipse 550 | PW600 Family	Y	Y
Falcon 10X | Pearl	Falcon 10X | Pearl	Y	No Noise Data
Falcon 2000 | PW300 Family	Falcon 2000 | PW300 Family	Y	Y
Falcon 6X | PW800 Family	Falcon 6X | PW800 Family	Y	Y
Falcon 7X | PW300 Family	Falcon 7X | PW300 Family	Y	Y
Falcon 8X | PW300 Family	Falcon 8X | PW300 Family	Y	Y
Falcon 900 | TFE731	Falcon 900 | TFE731	Y	Y
G280 | HTF7000	G280 | HTF7000	Y	Y
G400 | PW800 Family	G400 | PW800 Family	Y	No Noise Data
G500 | BR700	G500 | BR700	Y	Y
G500 | PW800 Family	G500 | PW800 Family	Y	Y
G550 | BR700	G550 | BR700	Y	Y
G600 | PW800 Family	G600 | PW800 Family	Y	Y
G650 | BR700	G650 | BR700	Y	Y
G700 | Pearl	G700 | Pearl	Y	No Noise Data
G800 | Pearl	G800 | Pearl	Y	No Noise Data
Global 5500 | BR700	Global 5500 | BR700	Y	Y
Global 6500 | BR700	Global 6500 | BR700	Y	Y
Global 7500 | Passport	Global 7500 | Passport	Y	Y
Global 8000 | Passport	Global 8000 | Passport	Y	No Noise Data
Hondajet | HF120	Hondajet | HF120	Y	Y
Il-114 | TV3-117	Il-114 | TV3-117	Y	No Noise Data
Il-96 | PS-90	Il-96-400 | PS-90	Y	No Noise Data
Learjet 75 | TFE731	Learjet 75 | TFE731	Y	Y
Legacy 450/500 | HTF7000	Legacy 500 | HTF7000	Y	Y
Legacy 650 | AE3007	Legacy 650 | AE3007	Y	Y
E-190/195 | CF34	Lineage1000 | CF34	Y	Y
MS-21 | PD-14	MS-21 | PD-14	Y	No Noise Data
PC-24 | FJ44	PC-24 | FJ44	Y	Y
Phenom 100/300 | PW600 Family	Phenom 100EV | PW600 Family	Y	Y
Phenom 100/300 | PW500 Family	Phenom 300 | PW500 Family	Y	Y
Q400 | PW100 Family	Q400 | PW100 Family	Y	No Noise Data
SSJ | PD-8	SSJ | PD-8	Y	No Noise Data
SSJ | SaM146	SSJ-95LR | SaM146	Y	No Noise Data
Tu-154 | D-30	Tu-154 | D-30	Y	No Noise Data
Tu-214 | PS-90	Tu-214 | PS-90	Y	No Noise Data

Aeroplane Family	**Aeroplane Variant**	**First to Fail**	
		CO2	***Noise***
Vision | FJ33	Vision | FJ33	Y	Y

— END —